3.12 DEVELOPMENT OF A WSR-88D BASED PRECIPITATION ACCUMULATION ALGORITHM FOR QUANTITATIVE PRECIPITATION ESTIMATES OVER NORTHWEST OREGON

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1. INTRODUCTION

The Bureau of Reclamation (Reclamation) is working on a water resources project in northwest Oregon that uses WSR-88D (Weather Surveillance Radar - 1988 Doppler) based Quantitative Precipitation Estimates (QPE) over watersheds draining into reservoirs. The WSR-88D is also known as NEXt generation weather RADar or NEXRAD. Such QPEs are being used with Internet decision support tools to improve water management efficiency (e.g., the Agricultural WAter Resources Decision Support or AWARDS system, described by Hartzell et al., 2000). Standard WSR-88D precipitation products such as the hourly Digital Precipitation Array are described by Klazura and Imy (1993). The accuracy of such products over northwest Oregon, based on the default $Z_e = 300R^{1.4}$ relationship with no range correction, is not sufficient for Reclamation's operational needs. This Z_e-R relationship is intended for convective rain and not stratiform rain; also, it is known to be invalid for snowfall. The QPE problem is further complicated in the West by mountainous terrain, the ridge (1670 ft elevation) location of the Portland, OR, WSR-88D (KRTX) tower/antenna from which it views both ice particles and rain during the cool season (October-April), and other factors.

2. BACKGROUND

Reclamation meteorologists and programmers began development of a Snow Accumulation Algorithm (SAA) for the WSR-88D Operational Support Facility in June 1995. This project used the highest resolution Z_e data recorded (Level II), with 0.5 dBZ_e intervals and single bin (1E X 1 km) spatial resolution. An overview of the SAA was presented by Super and Holroyd (1997), and SAA development was described in detail by Super and Holroyd (1998).

Level II data are used as input to the Precipitation Processing Subsystem algorithm calculations associated with each WSR-88D. However, Level II observations are rarely available to non-NEXRAD agency users in real time. Consequently, Reclamation developed the means to use Level III reflectivities as input to a SAA (Super, 1998). This work was supported by Reclamation's Science and Technology (S&T) Program and the GEWEX Continental-Scale International Program (GCIP).

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Level III base reflectivity data are a NEXRAD Information Dissemination Service (NIDS) product available for the four lowest radar antenna tilts soon after each volume scan, with the same range bin spatial resolution as Level II data (1E X 1 km). But Level III Z_e observations are "degraded" to 5.0 dB resolution in precipitation scanning mode (4.0 dB in clear air mode). The poorer reflectivity resolution is presumably because the Level III reflectivity product is intended to be graphically displayed with only 16 levels of color. More levels (colors) would be difficult to interpret.

In the WSR-88D's precipitation mode, the Level III NIDS data are quantized into steps of 5.0 dBZ_e for 16 threshold levels, e.g., level 5 is the 20 dBZ_e threshold and indicates a Level II equivalent range from 20.0 to 24.5 dBZ_e. Reclamation's SAA adjusts the nominal value of 20 dBZ_e to 22 dBZ_e to account for typical distributions of reflectivity within the interval.

Prior to the 1998-1999 cool season, Reclamation's Bend, OR, Field Office requested that the AWARDS system be implemented for the Rogue River Basin project. The project area is within 100 km of the Medford, OR, WSR-88D (KMAX), to the NW through ENE. Reviewing atmospheric sounding, WSR-88D, and precipitation gage data for the October 1998 - May 1999 period revealed that in almost all instances, precipitation was widespread and orographically enhanced. Medford soundings from periods when precipitation was being recorded at the Medford Airport had an average freezing level height of 4,980 ft msl and an estimated average cloud top height of 15,830 ft msl. Because the 7,546 ft msl KMAX tower/antenna elevation was significantly above the average freezing level for precipitation soundings, it was concluded that KMAX largely observed snow and was a good candidate for implementing the SAA using NIDS Level III data.

The prototype SAA was intended for use with dry snow. Melting snow may produce bright band contamination and resulting overestimation. When considering the $Z_e = a S^ß$ relationship for dry snow, it was determined that ß = 2.0 was appropriate for several locations, and a change in the ß exponent of ± 0.2 has little practical significance (Super and Holroyd, 1998). For the SAA used in the High Plains, a was set to 150. However, the KMAX SAA uses an a of 100. Despite application of a seasonal average range correction scheme, the accuracy of snow estimates still degraded with increasing distance (range) from each radar. The range correction factor (CF) used was: $1.00000 - 0.00500r + 0.0001428r^2$, where r is the range from the radar. This CF was applied only at ranges greater than 35 km (Hartzell and Super, 2000).

3. PRECIPITATION ACCUMULATION ALGORITHM

In October 1999, Reclamation's Bend, OR, Field Office requested that the AWARDS system (Hartzell et al., 2000) be implemented for the Tualatin project, which is located southwest of Portland, OR, around the town of Forest Grove. Water for irrigation comes primarily from the watershed above Scoggins Dam, which is located at an azimuth of about 235 degrees and a range of 35 km from the Portland WSR-88D (KRTX) antenna.

Long-term (1961-1990) mean yearly precipitation data for Portland, OR show the heaviest precipitation months to be October-April. Almost all precipitation during the cool season over the coastal areas inland to the Cascade Range in Oregon and Washington occurs in widespread precipitation events. During the last two cool seasons, the 1670 ft elevation of the KRTX antenna was almost always below the melting level in the atmosphere. The detected precipitation type was normally a mixture of snow and rain, depending on elevation. Consequently, the dry snow SAA would not be applicable, and a mixed phase Precipitation Accumulation Alogrithm (PAA) that uses Level III base reflectivity data with 5 dB resolution (precipitation mode) had to be developed. This consisted of making appropriate revisions to the SAA. Because the average height of the melting level was above the WSR-88D antenna, bright band contamination problems were anticipated in the data.

After testing several $Z_e = aR^ß$ relationships and observing that cool season precipitation over the coastal areas was much more stratiform than convective, the Marshall-Palmer relationship, $Z_e = 200R^{1.6}$ was implemented for operational testing of the PAA. Testing was done in northwest Oregon from October 1999 through May 2000. The $Z_e = aR^ß$ relationships that were tried are listed in Table 1. This table lists the rainfall rate comparison, in inches/hour, for the four relationships at various reflectivity levels.

Table 1. Rainfall Rate Comparison (in/hr)

dBZ_e	Z_e=300$R^{1.4}$	Z_e=200$R^{1.6}$	Z_e=150$R^{2.0}$	Z_e=100$R^{2.0}$
10	0.00	<0.01	0.01	0.01
15	0.01	0.01	0.02	0.02
20	0.02	0.03	0.03	0.04
25	0.04	0.05	0.06	0.07
30	0.09	0.11	0.10	0.12
35	0.21	0.22	0.18	0.22
40	0.48	0.45	0.32	0.39
45	1.10	0.93	0.57	0.70
50	2.50	1.91	1.02	1.25
55	5.68	3.93	1.81	2.21

Other settings required for the PAA include the WSR-88D's operational mode (precipitation or clear air), the Precipitation Detection Threshold (MNDBZ), and the Maximum Precipitation Threshold (MXDBZ). The setting of good precipitation thresholds is essential for obtaining representative radar precipitation estimates. For Tualatin Project operations during the 1999-2000 cool season, the minimum value used to calculate precipitation (MNDBZ) was set to 15 dBZ_e (R = 0.01 in/hr) and the maximum precipitation threshold (MXDBZ) was set to 45 dBZ_e (R = 0.93 in/hr). A range (r, from KRTX) correction factor (CF) of $1.000000 - 0.015000r + 0.000125r^2$ for r > 120 km was applied and tested, along with the $Z_e = 200R^{1.6}$ relationship. This CF increased the precipitation estimate by a factor of about 3.5 at the 200 km range. Using a CF beginning at 35 km from KRTX, as is done in the SAA, resulted in significant overestimates from 35 to120 km; therefore, a CF was not applied for this range.

4. ANALYSIS OF 1999-2000 COOL SEASON DATA

WSR-88D, precipitation gage, and atmospheric sounding data were collected for the October 1999 through May 2000 period. As of the writing of this paper, we have completed data analysis for October - December 1999. The analysis unit selected was the 24-hr local time day.

The primary objective of our work for Reclamation's Tualatin project is to develop near real time decision support tools for water managers that should result in improved efficiency in water operations. Improved QPEs are a critical part of these tools, which can be accessed via the Internet. Figure 1 shows the coverage area of the KRTX WSR-88D; the primary areas of interest are boxes enclosed by dashed lines. When viewing this image on the Internet, the user can click in either box for an enlarged image of the area within the box. The Internet URL is http://yampa.earthsci.do.usbr.gov:8080/awards/Or/Tualatin.html.

Figure 2 shows the KRTX hybrid scan file. The dark areas are where data from the second antenna tilt are used because the lowest tilt is blocked. The locations of eleven precipitation gages used in this study are shown (compare to Figure 1). The IDs SEC and SDM are SNOTEL sites located within the watershed above Scoggins Dam. As stated earlier, this area provides most of the water supply for the Tualatin project. Therefore, it is the area where good QPEs are needed.

A total of 38 precipitation days were selected for analysis from the October - December 1999 period. The criteria used in the selection process were: (1) there must have been precipitation measured by both of the SNOTEL storage gages (SEC and SDM) and Reclamation's site in Forest Grove (FOGO); (2) the precipitation had to be widespread over the Oregon coastal area; and (3) the KRTX NIDS Level III base reflectivity volume scan data for the 24-hr local time day must be complete. KSLE is also the location for the atmospheric soundings used in this study. For the 38 days, there were 33 KSLE soundings made during precipitation events. These soundings were all very similar to each other, with an average freezing level height of 6,450 ft msl, and an estimated average cloud top height and temperature of 14,000 ft msl and -12.9EC, respectively. Strong southwest wind flow was usually present, with 850 mb winds averaging 230 degrees at 38 kts.

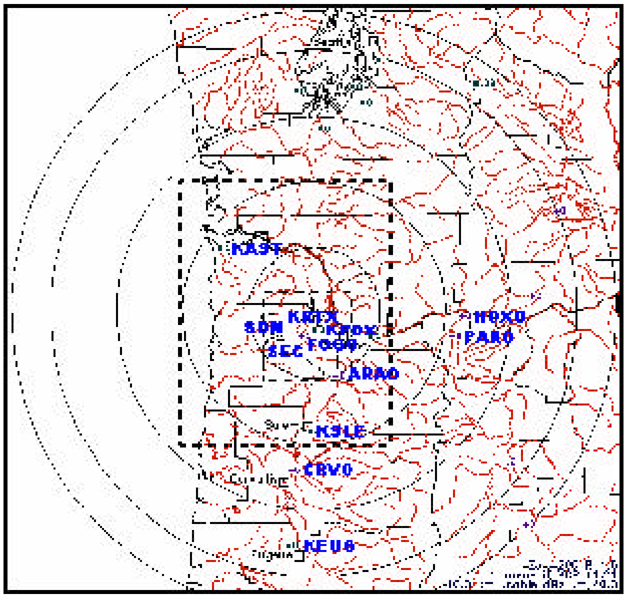

Figure 1. Shown is the 230 km radius coverage area of the Portland, OR (KRTX) WSR-88D with inner 50 km radius circles from KRTX.

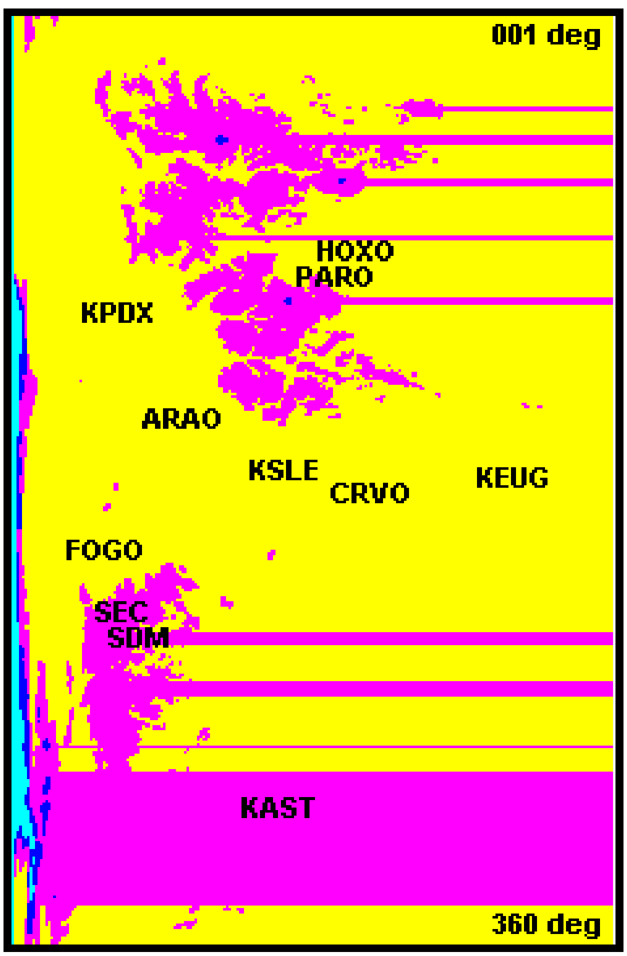

Figure 2. Original KRTX hybrid scan file. The x-axis is the range (1 - 230 km) from KRTX, and the y-axis is the azimuth (1-360 degrees).

Bright band contamination was a significant problem on most of the days; however, there were some days when such contamination was not evident. Figure 3 shows a KSLE sounding on one of the bright band contamination days. On this day (10 November 1999), the radar precipitation (average of nine range bins over KSLE) to gage-measured precipitation for KSLE exceeded 150 %, regardless of which $Z_e = aR^{ß}$ relationship was used. Such comparisons can only be estimates because of the effects of strong low-level horizontal winds below the beam and precipitation gage inaccuracies and sampling errors (Groisman and Legates, 1994).

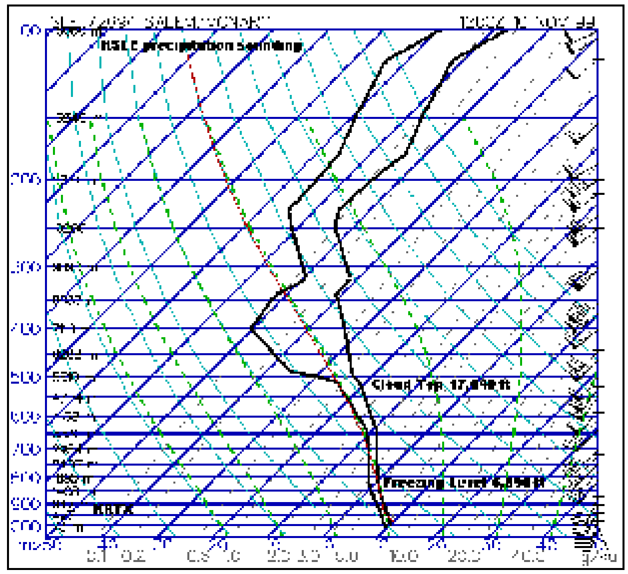

Figure 3. Example of a Salem (KSLE) sounding taken during a widespread precipitation event on November 10, 1999 at 12Z (or 1200 UTC, 4 p.m. PST).

Figure 4 shows the 0.5 degree elevation angle radar beam at the 185 degree azimuth from KRTX and five gage locations used in this analysis. Comparison with Figure 2 shows that these gages are in a valley where the 0.5 degree beam is not blocked. The Portland ASOS gage (KPDX) was also unobstructed; however, the daily accumulations appeared low in comparison to FOGO. More information is needed on the location and accuracy of this gage. The Astoria, OR, ASOS site (KAST) is in the shadow of the ridge where KRTX is located. Consequently, the 1.5 degree radar beam was used, resulting in KAST having the poorest radar-to-gage comparison. The second beam was also used for radar precipitation estimates over SEC and SDM. Figure 4 also shows KSLE 10 November 1999, 12Z sounding information. With the freezing level at just under 6,000 ft msl, potential bright band contamination was nearly centered over KSLE (see Figure 4).

Table 2 lists all 11 gages that were used in this analysis by range from KRTX. The column labels that include "set 1" through "set 6" list the 38-day average radar-to-gage precipitation ratios (as percentages) for various $Z_e = aR^{ß}$, MNDBZ and MXDBZ settings.

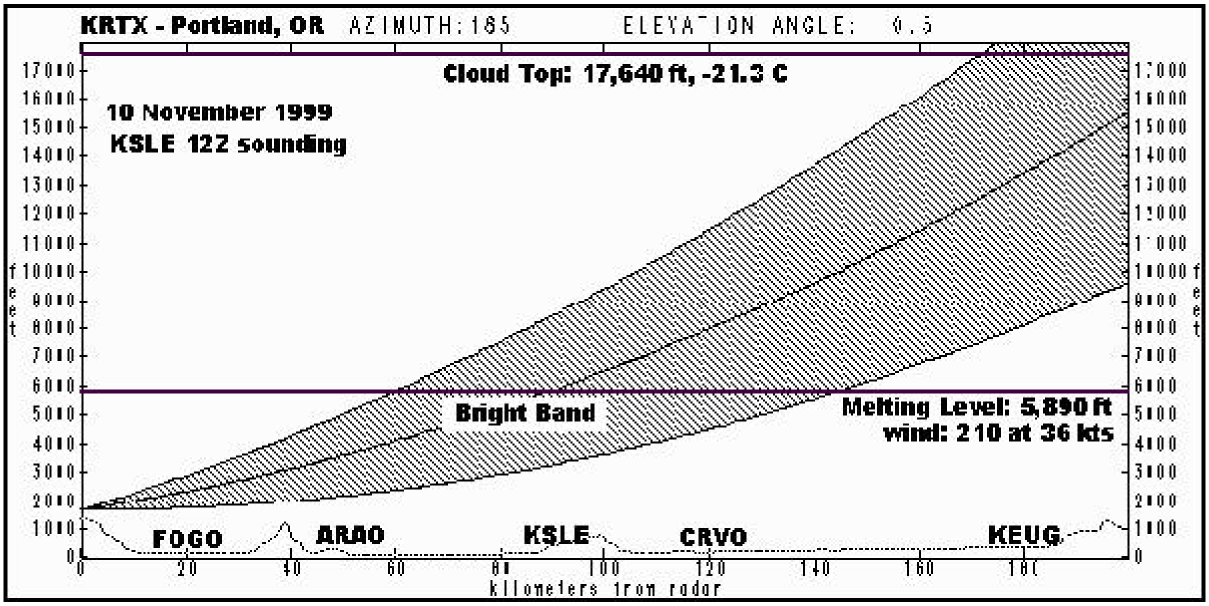

Figure 4. Ridge location of KRTX (1,670 ft msl), topography under the 0.5 degree elevation angle radar beam along the 185 degree azimuth from KRTX, and the ranges of five precipitation gages under the beam. The Salem (KSLE) sounding data are from the Skew-T plot shown in Figure 3.

Table 2. Comparison of radar estimated 24-hr precipitation with gage accumulations. The columns under the settings give the average ratio of radar (r) to gage (g) in percent (%), for the 38 days.

Site	Range (km)	Az. (deg)	Elev. (ft)	$100R^{2.0}$ r/g (%) set 1	$150R^{2.0}$ r/g (%) set 2	$200R^{1.6}$ r/g (%) set 3	$200R^{1.6}$ r/g (%) set 4	$300R^{1.4}$ r/g (%) set 5	$300R^{1.4}$ r/g (%) set 6
FOGO	20	207	180	127	103	94	100	95	89
KPDX	32	116	26	148	120	111	114	105	97
SEC	33	232	2000	88	72	68	76	72	70
SDM	36	240	3250	82	67	63	72	67	65
ARAO	51	161	140	154	125	118	123	110	103
KAST	86	305	10	52	42	37	37	32	27
KSLE	90	181	210	147	119	113	118	107	102
PARO	107	100	1480	112	92	86	88	80	73
HOXO	112	91	560	137	112	105	107	98	88
CRVO	122	188	230	119	96	90	95	85	79
KEUG	178	186	364	142	115	111	89	32	23

Settings used in computing 24-hr radar ppt/gage ppt ratio (%)

1 $Z_e = 100\ R^{2.0}$, MNDBZ = 10 dBZ, MXDBZ = 45 dBZ with CF 1201 > 120 km
2 $Z_e = 150\ R^{2.0}$, MNDBZ = 10 dBZ, MXDBZ = 45 dBZ with CF 1201 > 120 km
3 $Z_e = 200\ R^{1.6}$, MNDBZ = 10 dBZ, MXDBZ = 40 dBZ with CF 1202 > 120 km
4 $Z_e = 200\ R^{1.6}$, MNDBZ = 15 dBZ, MXDBZ = 45 dBZ with CF 1201 > 120 km
5 $Z_e = 300\ R^{1.4}$, MNDBZ = 15 dBZ, MXDBZ = 50 dBZ
6 $Z_e = 300\ R^{1.4}$, MNDBZ = 20 dBZ, MXDBZ = 53 dBZ

Range Correction Factor (CF) 1201 = $1.000000 - 0.015000R + 0.0001250R^2$
Range Correction Factor (CF) 1202 = $1.000000 - 0.019000R + 0.0001583R^2$

Figure 5 shows the means and standard deviations of 24-hr radar-to-gage precipitation accumulation ratios (as percent) for the 38 days combined. The PAA test settings used in this study are listed at the bottom of Table 2. KEUG, at 178 km from KRTX, was not used in the analysis for Figure 5, because the CF was not constant.

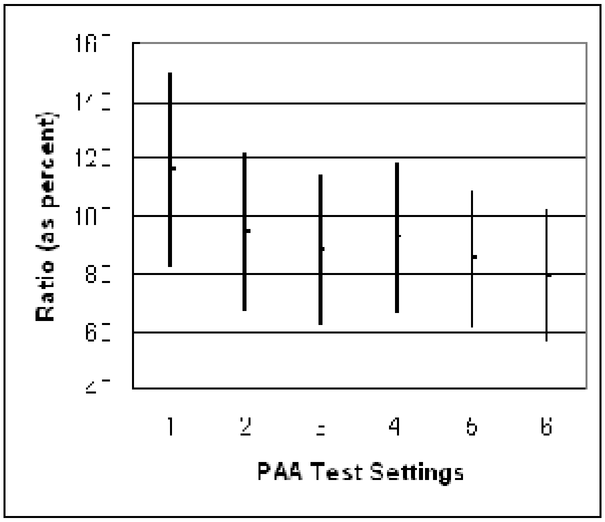

Figure 5. Mean and standard deviations for the six PAA test settings (see bottom of Table 2) at 10 sites.

5. FINDINGS AND CONCLUSIONS

Bright band contamination was common and resulted in precipitation overestimates. Possible methods to minimize this problem in the PAA will be investigated.

Blockage of the 0.5 degree beam by the terrain surrounding KRTX requires precipitation estimates to be derived from 1.5 degree beam data. This usually results in underestimation of precipitation. It is planned to add vertical profile of reflectivity adjustments in the PAA to help correct this problem.

Adding a range correction factor beyond 120 km from KRTX to compensate for the radar beam overshooting precipitation can improve radar estimates at longer ranges (see KEUG in Table 2).

$Z_e = 150\ R^{2.0}$ with MNDBZ=10 and MXDBZ=45 (set 2) gave the best overall fit for the sample data. However, $Z_e = 200\ R^{1.6}$ with MNDBZ=15 and MXDBZ=45 (set 4) was similar.

Within 50 km of KRTX over Reclamation's Tualatin project, $Z_e = 200\ R^{1.6}$ with MNDBZ=15 and MXDBZ=45 (set 4) gave radar-to-gage ratios closest to 100%.

When the PAA used only 1.5 degree beam data within 50 km of KRTX, $Z_e = 100\ R^{2.0}$ (set 1) gave the best precipitation estimates.

Conclusion: there is no single Z-R relationship that is best for all radar ranges and antenna tilts.

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